~~Title:~~ Earth-Abundant Metal Catalysts: Exploring the ~~Potentials~~Potential of Iron, Cobalt, and ~~Nickil~~Nickel for Sustainable Chemical Reactions and Energy Applications

Abstract

~~The development of affective~~Developing effective and affordable catalysts based on ~~earth-abundant~~ metals abundant in the Earth, such as iron, cobalt, and ~~nickil~~nickel, is essential for realizing sustainable chemical production and energy conversion processes. These metals ~~show~~are a ~~much~~ more attractive alternative to the rare and expensive metals~~, which are~~ currently used in many catalysts. This paper reviews recent advances in the ~~developing~~development of earth~~-~~-abundant metal catalysts, focusing on their ~~application~~applications in various chemical reactions relevant to energy conversion and storage. ~~Also, the~~The challenges and ~~future~~ prospects for research in ~~this~~these areas are also discussed, ~~emphasising~~emphasizing the need for interdisciplinary collaboration and innovative strategies ~~for the~~to design and ~~optimisation of~~optimize these sustainable catalysts.

Introduction

Catalysts ~~play a serious role in driving~~drive various chemical reactions by improving their efficiency~~,~~ and selectivity~~,~~ and reducing ~~the~~ energy requirements (Crabtree, 2010~~). A lot of~~). Many currently used catalysts are based on rare and expensive metals, such as platinum, ~~Pd~~palladium, and rhodium, which have limited availability and can be economically and environmentally ~~insustainable~~unsustainable (Chirik, 2011). ~~This can be contrasted with~~In contrast, earth-abundant metals, ~~like~~including iron, cobalt, and ~~nickil, who~~nickel, offer an attractive alternative for ~~the development of~~ sustainable catalysts because of their low cost~~,~~ and widespread availability (Nishibayashi 2015). This paper focuses on the potential ~~using~~use of these earth-abundant metals as catalysts for various chemical reactions, including those relevant to energy conversion and storage.

Iron-Based Catalysts

Iron is the most abundant transition metal in the ~~Earth's~~Earth's crust and has been extensively studied as a potential catalyst for various ~~and diverse~~ chemical reactions (Bauer, 2015). One notable example is the Haber~~-~~–Bosch process~~; which uses of iron-based catalyst~~, which involves the synthesis of ammonium from nitrogen and hydrogen using an iron-based catalyst (Schrock, 2006). Iron-based catalysts have also been investigated for their application in the Fischer~~-~~–Tropsch processes, which ~~translates~~converts synthesis gas (a mixture of carbon

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monoxide and hydrogen) into hydrocarbons and ~~oxygenates~~oxygenated hydrocarbons (Davis, 2011).

~~New, up-to-date~~

Recent research has ~~focussed~~focused on ~~the development of~~developing iron-based molecular catalysts~~,~~ that ~~can~~ mimic the active sites of natural enzymes~~,~~ (e.g.~~ hydrojenases~~., hydrogenases and nitrogenases~~, which are~~) involved in the activation and conversion of small molecules (Rauchfuss, 2009). These biomimetic catalysts ~~have been shown to be especialy~~are especially promising for the reduction of protons to hydrogen, nitrogen fixation, and the ~~activating~~activation of carbon dioxide and other small ~~atoms~~molecules (Artero & Fontecave, 2013). ~~But,~~However, improving the stability and activity of these iron~~-~~-based molecular catalysts is still ~~need to be improved~~required for practical applications.

Cobalt-Based Catalysts

Cobalt is ~~also a~~ another earth-abundant~~-earth~~ metal that has been studied for its potential use ~~for~~as a catalyst ~~agent~~ in various chemical reactions (Anjana & Sreekanth, 2015). ~~–~~Cobalt-based catalysts have been widely used in the Fischer~~-~~–Tropsch ~~processes, where~~process; they exhibit large activity and high selectivity for ~~production of longchain~~producing long-chain hydrocarbons (Khodakov et al., 2007~~).~~).

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~~In recent years~~Recently, cobalt-based molecular catalysts ~~has~~have been investigated for ~~there~~their application in the electrochemical and photochemical reduction of protons to ~~Hydrogen~~hydrogen (Sun et al., 2015). These catalysts have shown promising activity and stability under ~~a wide range of~~various conditions; ~~making them atttractive~~thus, they are attractive candidates for ~~the development of~~developing sustainable hydrogen production technologies (Artero et al~~,~~., 2011). Cobalt-based catalysts ~~has~~have also been explored for their ~~potent~~potential use in the electrocatalytic reduction of carbon dioxide to ~~fomate~~formate, a valuable chemical feedstock (Kumar et al., 2016~~., 2016). Still, further~~). Further optimization of the catalytic performance and selectivity of these cobalt-based catalysts is needed for practical applications~~..~~.

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~~Nickil-Biased~~

Nickel-Based Catalysts

~~Nickil~~Nickel is ~~another~~the third earth-abundant metal that has attracted considerable attention for ~~it's~~ potential use as a ~~catalyzt of various chemical reactions~~catalyst (Kumar and Jain, 2012). ~~Nickil bases~~Nickel-based catalysts have been widely used in ~~the hydrogenaton~~

~~of~~hydrogenating unsaturated hydrocarbons~~,~~ and ~~the production of~~producing chemicals from biomass-derived feedstocks (Chen et al., 2014).

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~~In recent years, nickil~~Nickel-based molecular catalysts have recently been ~~made~~developed for the electrochemical and photochemical reduction of protons to hydrogen~~,~~ and ~~also~~ the oxidation ~~of~~ of hydrogen to protons (Tard & Pickett, 2009). These catalysts exhibit high activity and stability under ~~a variety of~~various conditions~~, making them~~; they are promising candidates for ~~the development of~~ sustainable development (Canaguier et al., 2012). ~~Nickil~~Nickel-based catalysts have also been investigated for their potential use in the electrocatalytic reduction of carbon dioxide to carbon ~~monooxide~~monoxide, a key ~~indermetiate~~intermediate in ~~the production of~~producing liquid fuels and ~~chemical~~chemicals (Jouny et al., 2018). However, ~~the development of~~developing more selective and efficient ~~nickil~~nickel-based catalysts for carbon dioxide reduction remains a challenge.

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Challenges and Future ~~Prospectives~~Prospects

The development of earth-abundant metal catalysts for ~~sustianable~~sustainable chemical reactions and energy applications ~~face~~faces several challenges, including the need ~~of~~for a better understanding of the fundamental mechanisms of catalysis, the design of catalysts with the desired properties, and the scaling up of their production for practical applications (Chirik, 2011~~].~~). Interdisciplinary research involving ~~synthetical~~synthetic chemistry, materials science, computational chemistry, and engineering will be crucial in addressing these challenges and advancing the field of sustainable catalysis (Crabtree, 2010).

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Future research should ~~definitely~~ focus on ~~the developmant of~~developing innovative strategies for the design and optimization of ~~the~~ earth-abundant metal catalysts, such as the use of ligands and supports to control their electronic and ~~sterec~~ steric properties~~, as well as~~ and the application of computational methods to predict and design new catalysts with the desired properties (Nishbayashi, 2015). ~~Also, research~~Research efforts should ~~be directed towards the investigation of~~also investigate novel catalytic systems and reaction ~~pathway~~pathways that could lead to the development of more ~~efficacious~~effective and selective processes for ~~the conversion of~~converting sustainable resources to ~~valaubIe~~valuable chemicals and fuels (Davis, 2011).

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Conclusion

~~The development of~~Developing effective and affordable catalysts based on earth-abundant metals, such as iron, cobalt, and ~~nickil~~nickel, is ~~principal for realising~~critical to realizing sustainable chemical production and ~~sustainable~~ energy conversion processes. Recent advances in the development of these catalysts have shown promising results for various chemical reactions relevant to energy conversion and storage. However~~.~~, further research is needed to address the challenges associated with the design, ~~and~~ optimization, and scale-up of these sustainable ~~Catalysts~~catalysts. Interdisciplinary collaboration and innovative strategies will be crucial for advancing the field of sustainable catalysis and unlocking the ~~fullest~~full potential of earth-abundant metal catalysts.

~~***Reference***~~

References

[1] G.W. Crabtree, "The environment and the need for new catalysts," *Catal. Today*, vol. 154, no. 3–4, pp. 207–212, 2010.

[2] P. J. Chirik, "Earth-abundant metal catalysts for alkene hydrosilylation," *Nature Chem.*, vol. 3, no. 10, pp. 773–774, 2011.

Anjana, S. R., & Sreekanth, A. R.. Cobalt catalysts: a review. Catalysis Reviews, 57(4), 306-344.

Artero, V & Fontecave, M. (2013). Solar fuels generation and radical innovation: The need for a resource-based analysis. Energy Policy, 62, 8—12

Artero, V., Chavarot-Kerlidou, M., and Fontecave, M. (2011). Splitting Water with cobalt. Angewandte Chemie International Edition, 50(32), 7238-7266.

Bauer, I., & KnölBauer, I., & Knölker, H. J. (2015). Iron catalysis in organic synthesis. Chem. Rev., 115(9), 3170-3387.

Canaguier, S., Artero, V., & Fontecave, M. (2012). A Ni bis(diphosphine)-based electrocatalytic platform related to hydrogenases. Inorganica Chimica Acta, 380, 426-433.

Chen, X., Engle, K. M., Wang, D. H., & Yu, J. Q. (2009. Palladium(II)-catalyzed C–H activation/C–C cross-coupling reactions: versatility and practicality. Angewandte Chemie International Edition, 48(28), 5094-115.

Chirik, P. J. (2011). Earth-abundant metal catalysts for alkene hydrosilylation. Nature Chemistry, 3(10), 773-774.

Crabtree, G. W., (2010). Energy, The Environment and The Need for New Catalysts. Catalysis Today; 154 (3-4); 207-212.

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Davis, S. J., & Socolow, R. H. (2014). Commitment accounting of CO_2 emissions. Environmental Research Letters, 9(8), 084018.

Jouny, M., Luc, W., & Jiao, F. (2018). General techno-economic analysis of CO_2 electrolysis systems. Industrial & Engineering Chemistry Research, 57(6), 2165-2177.

Khodakov, A. Y., Chu, W., & Fongarland, P. (2007).Advances in the development of novel cobalt Fischer-Tropsch catalysts for synthesis of long-chain hydrocarbons and clean fuels. Chemical Reviews, 107(5), 1692-1744.

Kumar, B., & Jain, S. L. (2012). ~~Nickil~~Nickel-catalyzed coupling reactions: approaches toward sustainability. ChemSusChem, 5(11), 2038-2052.

Kumar, B., Smirnov, A., Luo, H., Dong, W., & Stephan, D. W. (2016). An efficient and robust iron-based catalyst for the electrochemical reduction of CO_2 to formate. Journal of Materials Chemistry A, 4(48), 18748-18754.

Nishibayashi, Y. (2015). Recent progress in transition-metal-catalyzed reduction of molecular dinitrogen under ambient reaction conditions. Inorganica Chimica Acta, 431, 41-51.

Rauchfuss, T. B. (2009). Strategies for the synthesis of hydrogenase active site mimics. Inorganica Chimica Acta, 362(3), 785-792

Schrock, R. R. (2006). Reduction of dinitrogen. Proceedings of the National Academy of Sciences, 103(46), 17087-17094.

Sun, Y., Bigi, J. P., Piro, N. A., Tang, M. L., Long, J. R., & Chang, C. J. (2013). Molecular cobalt pentapyridine catalysts for generating hydrogen from water. Journal of the American Chemical Society., 133(45), 9212-9221~~..~~.

Tard, C., & Pickett, C. J. (2009). Structural and functional analogues of the active sites of the [Fe]-, [NiFe]-, and [FeFe]-hydrogenases. Chemical Society Reviews, 38(1), 89-99.

Sun, L., Ramesh, S., & Brennessel, W. W. (2015). Cobalt catalysts for the hydrogenation of CO_2 to formate. Inorganica Chimica Acta, 424, 273-278.

Wang, M., Chen, L., & Sun, L. (2012). Recent advances in electrochemical hydrogen production at low overpotentials. Journal of Power Sources, 226, 235-242.

Xu, Y., & Lotero, E. (2017). Earth-abundant transition-metal catalysts for the electrochemical reduction of CO2 to formate. ChemSusChem: 10:(21): 4092-4103.

Yan, Y., Du, J., Gilroy, K. D., & Xia, Y. (2016). Recent progress in earth-abundant metal-based heterogeneous electrocatalysts for water oxidation. ChemSusChem, 9(16), 1975-1987.

Zhang, P. Wang, M., & Yang, y. (2017). Recent developments in earth-abundant metal-based catalysts for electrochemical water splitting. Journal of Materials Chemistry A,5(15),6656-6679.